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# Inconstancy: An ontology repair plan for adding hidden variables

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The 17th CIAO Workshop



# Outline

- 1 Overview
- 2 "Inconstancy"
- 3 Examples
  - MODified Newtonian Dynamics (MOND)
  - Boyle's Law
- 4 Discussion



# Ontology repair plans

Ontology repair needed for changing environment

- Not just changes to *beliefs*, but to *signatures* as well
- Atomic operations: split functions, add arguments, etc.

The "Inconstancy" ontology repair plan

- Triggered by conflict between predicted independence and observed dependence
- Apply to two historical repairs in physics
- Implemented in  $\lambda$ Prolog (*GALILEO - Guided Analyses of Logical Inconsistencies Lead to Evolved Ontologies*)



# The "Inconstancy" ontology repair plan

## Trigger

$$\begin{aligned}
 O_t &\vdash \text{stuff}(\vec{x}) ::= c(\vec{x}) \\
 O_s(V(\vec{s}, \vec{b}_1) = v_1) &\vdash \text{stuff}(\vec{s}) = c_1(\vec{s}), \dots \\
 O_s(V(\vec{s}, \vec{b}_n) = v_n) &\vdash \text{stuff}(\vec{s}) = c_n(\vec{s}), \\
 \exists i \neq j. O_t &\vdash c_i(\vec{s}) \neq c_j(\vec{s})
 \end{aligned}$$

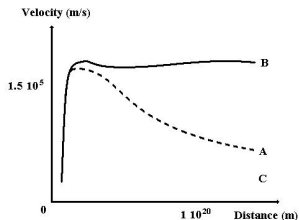
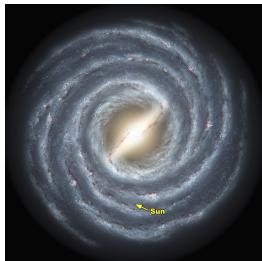
## Add variad

$$\nu(\text{stuff}) ::= \lambda \vec{y}, \vec{x}. F(c(\vec{x}), V(\vec{x}, \vec{y}))$$

## Create new axioms

$$\begin{aligned}
 Ax(\nu(O_t)) &::= \{ \phi \{ \text{stuff} / \nu(\text{stuff})(\vec{y}) \} \mid \phi \in Ax(O_t) \setminus \\
 &\quad \{ \text{stuff}(\vec{x}) ::= c(\vec{x}) \} \} \cup \\
 &\quad \{ \nu(\text{stuff}) ::= \lambda \vec{y}, \vec{x}. F(c(\vec{x}), V(\vec{x}, \vec{y})) \} \\
 Ax(\nu(O_s(V(\vec{s}, \vec{b}_i) = v_i))) &::= \{ \phi \{ \text{stuff} / \nu(\text{stuff})(\vec{b}_i) \} \mid \phi \in Ax(O_s(V(\vec{s}, \vec{b}_i) = v_i)) \}
 \end{aligned}$$

# MOdified Newtonian Dynamics (MOND)



- Newtonian theory of gravity predicted that objects further out will have lower velocities
- The observed velocities of those objects are almost constant!
- MOND - The gravitational force ( $F = \frac{G \times M \times m}{r^2}$ ) is different at low accelerations.

# Application to MOND

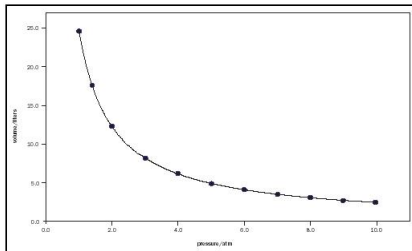
## Example

$$\begin{array}{ll}
 O_t \vdash & G ::= 6.67 \times 10^{-11} \\
 O_s(\text{Acc}(S_1) = A_1) \vdash & G = M2OV^{-1}(OV(S_1), \text{Mass}(S_1), \\
 & \lambda s \in \text{Spiral} \setminus \{S_1\}. (\text{Posn}(s), \text{Mass}(s))) (= G_1) \\
 & \vdots \\
 & \vdots \\
 O_s(\text{Acc}(S_n) = A_n) \vdash & G = M2OV^{-1}(OV(S_n), \text{Mass}(S_n), \\
 & \lambda s \in \text{Spiral} \setminus \{S_n\}. (\text{Posn}(s), \text{Mass}(s))) (= G_n) \\
 \exists i \neq j. O_t \vdash & G_i \neq G_j
 \end{array}$$

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$$\begin{array}{ll}
 \nu(O_t) \vdash & \nu(G) ::= \lambda s. F(6.67 \times 10^{-11}, \text{Acc}(s)) \\
 \nu(O_s(\text{Acc}(S_1) = A_1)) \vdash & \nu(G)(S_1) = M2OV^{-1}(OV(S_1), \text{Mass}(S_1), \\
 & \lambda s \in \text{Spiral} \setminus \{S_1\}. (\text{Posn}(s), \text{Mass}(s))) (= G_1) \\
 & \vdots \\
 & \vdots \\
 \nu(O_s(\text{Acc}(S_n) = A_n)) \vdash & \nu(G)(S_n) = M2OV^{-1}(OV(S_n), \text{Mass}(S_n), \\
 & \lambda s \in \text{Spiral} \setminus \{S_n\}. (\text{Posn}(s), \text{Mass}(s))) (= G_n)
 \end{array}$$

# Boyle's Law



- Boyle's law states that, at a fixed temperature, the pressure and the volume of a gas are inversely proportional, i.e.  
$$\text{pressure} \times \text{volume} = k$$
- The ideal gas law:  $\text{pressure} \times \text{volume} = k \times \text{temperature}$



# Application to Boyle's Law

## Example

$$O_t \vdash Boyle(gas) ::= \lambda mom. P(gas, mom) \times V(gas, mom) = K(gas)$$

$$O_s(T(Gas, Mom_1) = T_1) \vdash Boyle(Gas) = P(Gas, Mom_1) \times V(Gas, Mom_1) (= K_1)$$

$$\vdots$$

$$O_s(T(Gas, Mom_n) = T_n) \vdash Boyle(Gas) = P(Gas, Mom_n) \times V(Gas, Mom_n) (= K_n)$$

$$\exists i \neq j. O_t \vdash K_i \neq K_j$$

$$\nu(O_t) \vdash \nu(Boyle) ::= \lambda mom, gas. F(K(gas), T(gas, mom))$$

$$\nu(O_s(T(Gas, Mom_1) = T_1)) \vdash (\nu(Boyle)(Mom_1))(Gas) = P(Gas, Mom_1) \times V(Gas, Mom_1) (= K_1)$$

$$\vdots$$

$$\nu(O_s(T(Gas, Mom_n) = T_n)) \vdash (\nu(Boyle)(Mom_n))(Gas) = P(Gas, Mom_n) \times V(Gas, Mom_n) (= K_n)$$



# Conservativity

"Inconstancy" is a conservative extension if:

- The definition of *stuff* remains

...Create new axioms

$$\begin{aligned}
 Ax(\nu(O_s(V(\vec{s}, \vec{b}_i) = v_i))) &::= \{\phi\{\text{stuff}/\nu(\text{stuff})(\vec{b}_i)\} \mid \phi \in Ax(O_s(V(\vec{s}, \vec{b}_i) = v_i))\} \\
 Ax(\nu(O_t)) &::= \{\phi\{\text{stuff}/\nu(\text{stuff})(\vec{y})\} \mid \phi \in Ax(O_t) \setminus \\
 &\quad \{\text{stuff}(\vec{x}) ::= c(\vec{x})\}\} \cup \\
 &\quad \{\nu(\text{stuff}) ::= \lambda \vec{y}, \vec{x}. F(c(\vec{x}), V(\vec{x}, \vec{y}))\}
 \end{aligned}$$

- The ontology setup enables conservativity to be achieved

Conservativity is not guaranteed



# Problems solved by adding arguments

## Unexpected variation

- Add the parameters (variad) causing variation
- Approximate the new function by regression
  - MOND:  $F(6.67 \times 10^{-11}, \text{Acc}(s))$  returns  $6.67 \times 10^{-11}$  or a value proportional to  $\text{Acc}(s)^2 \times \text{Rad}(s)^2$ , depending on  $\text{Acc}(s)$
  - Boyle's Law:  $F \equiv \times$  (as required by the ideal gas law!)



# Problems solved by adding arguments

## Argument specialisation

- Refine arguments

### Example

$O_t \vdash \text{SpecHeat}(o, t) = k$  (specific heat of  $o$  at  $t$ )

( $\text{SpecHeat}(o, t)$  is  $\text{Temp}(o, t)$  used in the latent heat example)

- $\text{SpecHeat}$  is too abstract
- We know the specific heat of an object is: heat capacity  $\times$  mass  $\times$  difference in temperature ( $=cm\Delta T$ )

$\nu(O_t) \vdash \nu(\text{SpecHeat})(\text{CapConst}(o), \text{Mass}(o), \text{Tmpt}(o, t)) = k$

- Again, approximate the new function by regression
- $\nu(\text{SpecHeat}(o, t)) \equiv \times$



# Summary

The "Inconstancy" ontology repair plan:

- Triggered by conflict between predicted independence and observed dependence
- Introduce a new function relating the constancy with the variad
- Approximate the new function using regression
- Implemented in Terzo and Teyjus ( $\lambda$ Prolog) - GALILEO
- Other suggested repairs?



**Questions?**

